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"SENSIBLE TEMPERATURES."

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On hot summer days people in our large cities constantly complain that the temperatures recorded at the local Weather Bureau stations are much too low, and hence do not really represent the heat which people feel. In cold winter weather there is a similar objection, to the effect that the "official" temperatures are too high. This complaint arises from the fact that the public generally does not yet understand that "air temperature," as recorded by a standard thermometer, at some distance above the ground, in a shelter, protected from rain and sunshine and radiation from surrounding objects, does not and cannot indicate the temperature that we actually feel. The latter, which has been called "sensible temperature," and which, for want of a better term, we shall also thus designate, depends upon a great variety of factors which either do not enter into the so-called "air temperature" at all, or else are of secondary importance. For example, other meteorological conditions, such as the humidity of the air, the wind, the exposure to direct insolation and to reflected heat, and other more or less accidental physical conditions, such as the state of the human body, whether in good health or bad; the clothing, both as to kind and as to amount; the kind and the conditions of occupation; the nourishment of the body; even the mental condition of the individual—these and other factors enter into the account.

The human body is not like a thermometer in having no temperature of its own. It is a heat engine, which has a high internal temperature to keep up. This temperature is maintained by a slow internal combustion, in which the food plays the part of the fuel in the steam engine, and heat is constantly being lost from the skin, as well as from the lungs, in the process of respiration, and in warming the food taken into the stomach. Helmholtz believed that over three-quarters of the total loss takes place from the skin, and about 20% from the lungs. The loss from the lungs varies with the temperature and with the relative humidity of the air; the higher the temperature and the relative humidity, the less is the loss. The loss of water from the lungs is not directly noticeable. We estimate the moisture of the atmosphere chiefly by the loss of water from the skin, which amounts to about twice as much as that from the lungs.

The loss of heat from the external surface of the body, as has been clearly set forth by Van Bebber (of whose discussion the next few paragraphs are largely a summary), is accomplished by means of three familiar physical processes—conduction, radiation, evaporation. The amount of heat lost by conduction depends on the difference of temperature between the body and the surrounding air, and upon the conductivity of the air. Other things being equal, the colder the air the greater the cooling by conduction; the warmer the air, the less. Hence, conduction may be expected to be at a maximum in winter. Secondly, when there is wind, more heat is lost by conduction. Everyone knows that severe cold which may be easily endured when the air is calm may become unbearable when there is even a slight movement of the air. The springing up of a breeze on a bright, cold winter day may change the temperature which we feel from an agreeable one to one which is decidedly chilly, although the ordinary thermometer shows no change at all. The difference between calm cold and windy cold is very strikingly brought out in the reports from Arctic and Antarctic exploring expeditions. Temperatures of 20°, 30°, even 40°, below zero are described as being comfortable when there is no wind. Nansen, for example, says on one occasion, "The temperature to-day is 42° Fahr. below zero, but there is no wind, and we have not had such pleasant weather for walking for a long time; it feels almost mild when the air is still." Similar statements may be found in abundance in the writings of other Arctic explorers, it being frequently noted that the heavy clothing was too warm at these very low temperatures. In the Polar regions, then, the feeling of cold and the reading of the thermometer are not in any closer agreement than they are here. Naturally, high temperatures are more comfortable with some wind. Thirdly, the moisture of the air is an important consideration in this matter, for damp air is a better conductor than dry air. Hence, in winter, damp cold is so much harder to bear than dry cold. Hence the damp northeast winds on the New England coast in winter often feel colder than dry northwest winds which have a lower temperature, although the velocity may be the same in the two cases. Obviously, however, evaporation enters in to complicate this question of conduction somewhat.

The amount of heat lost by the body through radiation depends on the temperature and the radiating powers of surrounding objects, such as walls, pavements, vegetation, furniture, etc. It is conceivable that one should be so placed that the temperature of all surrounding objects, and of the air as well, should be just the same as the body temperature. In such a case the body would lose nothing by radiation. Nor would it lose anything by conduction. The only loss would be by evaporation, unless the air were saturated, in which case the conditions would be unbearable for any length of time. When radiation is checked, as by the presence of many persons crowded together, or by the proximity of hot walls, pavements, etc., the body may suffer serious consequences, as in the case of prostration by the heat and sunstroke, which, as is well known, usually attack people who are exposed under rather special conditions, as, *e.g.*, labourers on sewers and railways, masons and painters close to the walls of buildings, etc. When troops are on the march it has been shown that the men who suffer most are in the middle of the column, where they can lose least heat by radiation.

It is difficult to consider the adjustment of the body to the temperature conditions of the air without taking account of evaporation, which is of very great importance, and is almost always in operation to a greater or less degree. The human body in health has not a dry surface, like the dry-bulb thermometer, but is more or less moist because of the exudation of perspiration through the pores of the skin. When this moisture evaporates, the skin cools through the loss of heat which is required in the process of evaporation. Cramer has shown that the amount of water lost through perspiration during a hot summer day, if a man is kept at hard work, may reach between 7% and 8% of the weight of his body. Other things being equal, there is more evaporation the warmer, the drier, and the less quiet the air. The hotter the air, the greater its capacity for water vapour; the drier the air, the more water can still be evaporated into it; the more wind, the greater the opportunity for evaporation into the fresh supply of air which is constantly brought to the body. If the air be completely saturated at the body temperature, there can be no evaporation; but if the air be saturated below the body temperature, the body warms the air nearest it; in so doing the capacity of the air for water vapour is increased, and evaporation may then begin again. Even if the temperature of the air be 98.6°, unless the air be saturated, the body can cool by evaporation. It has been shown that, when the air is very dry, human beings can endure extraordinarily high temperature, as in the case of a man who stayed twenty minutes in dry air at 212°. Hot air in motion is much cooler than hot dry air at rest, and hot moist air is oppressive because there is little opportunity for evaporation. According to Blanford, the moist heat felt during a voyage across the Red Sea in August or September, with an air temperature of 90°, is much more oppressive than is the heat in the upper provinces of India during the blowing of the "hot winds," which are dry, when the temperature is 112° to 118°. The excessive dryness of these winds is made use of to keep the air of dwellings cooler by means of wet "tatties" hung over doors and windows. The more moist the air and the nearer its temperature to that of the body, the less difference does wind make. Dry air is in many respects an advantage at all seasons; in winter, because it makes the loss of heat by conduction less, and in summer, because it increases the loss of heat by evaporation.

Evidently, too, conduction enters into this question, for when the air is moist, evaporation is lessened, but conduction (unless the air be at the body temperature) is increased. On the whole, conduction is at a maximum in winter, and evaporation in summer. The very dry air of our furnace-heated houses in winter must be kept at a high temperature if we wish to be comfortable in it. We lessen the loss of heat from the body by conduction when we raise the temperature, but the loss by evaporation must be very great, because of the dryness of the air. If our houses were provided with a more moist heat we could be comfortable indoors with considerably lower temperature, because evaporation would be so much decreased. This has been experimentally determined by Dr. Henry J. Barnes, of Boston, who found that when the air in his office had a relative humidity of 27% the temperature had to be 70° or 71°, but when, by means of a "humidifier," which evaporated 4½ quarts of water daily, he had brought the air to a relative humidity of 53%, a temperature of 65° was comfortable. The temperatures in our houses are comfortable at about 70°, because the air is calm. If the air were in motion we should be uncomfortably cool, because of the increased evaporation.

The temperature which we feel does not depend solely on the temperature, the moisture, and the movement of the air. It is also influenced by the physical condition in which the body finds itself, for the body is not a passive object. When in health it adjusts itself to surrounding conditions by its own action. At low temperatures it seeks to check the loss of heat from its surface by contracting the pores, keeping the skin dry, and diminishing the amount of heat near the surface of the body. At high temperature, on the other hand, the pores are opened, perspiration is abundant, and the skin is cooled by evaporation. Furthermore, the relations of the body to the meteorological conditions of the atmosphere are affected to a very marked degree by the clothing. Many interesting experimental studies have shown that the differences between the temperature on the surface of the clothing and the air temperature decrease with an increasing number of articles of clothing between the skin and the outside air. The successive air strata between the different layers of clothing serve to modify the effect of the temperature and humidity of the air. Thus clothing, whose thickness, weight and texture may be varied at will, keeps the body from losing heat too rapidly to the surrounding air. Rübner has found that the temperature on the skin of a man dressed in the usual number of articles of winter clothing was about the same when the air temperature was 50° and when it was 79°. In this connection, the behaviour of different kinds of clothing materials in relation to moisture is naturally of considerable importance. Evidently, also, the questions whether the individual is taking exercise, how violent the exercise, and under what conditions with reference to surrounding objects, are all to be considered as controlling factors, for, obviously, on a cold day, two persons will experience very different temperatures if one of them is sitting still and the other is digging a trench.

The factor of exposure to radiation, whether directly from the sun, or from the sky, the surface of the earth, or other objects, also enters into the problem. Unlike a thermometer, which is in a shelter, protected from direct and reflected radiation so far as possible, human beings when out of doors are exposed to these radiations, and their feeling of heat is affected thereby. It has long been known that the energy of direct insolation is of great importance as a climatic factor, independently of the temperature of the air. In times of calm the air temperature may even be quite unimportant. Thus on calm, clear winter days, for example, if one sits in the sun, he may feel warm and comfortable while the air temperature is really very low. It is this climatic factor of direct solar radiation which is of great value in giving certain high mountain stations, in the Alps and elsewhere, their reputation as winter resorts. At Davos Platz, for example, and, similarly, in some of our own health resorts in Colorado, invalids may sit out in the sun and be comfortable on the coldest winter days. Reflected heat, as from water, or from a desert surface, or from a white wall, also affects one's feeling of heat or cold.

It is evident, then, that the sensation of temperature is the complex resultant of many variables, and that it must necessarily be an individual matter, for it depends upon so many physical, and even mental, conditions which differ in each individual case. The "sensible temperature," so called, is essentially a nervous sensation. This being so, it is also evident that no single instrument can possibly give an indication of the temperature which the body actually feels. There has, however, been a desire to find some simple expression for this "sensible temperature," and various suggestions have been made, both as to instrumental and as to non-instrumental expressions. The general public has shown a fondness for the use of "temperatures in the sun," *i. e.*, the readings of a dry-bulb thermometer exposed to sunshine, although these indications are well known to be practically worthless for any purposes of comparison, and to express no real climatic element. In 1826, Dr. W. Heberden, as Professor Abbe has pointed out, advanced the idea that sensible cold depends upon the rate at which the internal heat is carried away from the surface of the body, and proposed to use the rate of cooling of an ordinary thermometer as a measure of the sensible cold. About 1871, J. W. Osborne proposed to measure the sensible temperature by the time required for a mass of water, heated to the temperature of the human body, and contained in a paper cylinder, to cool. Osborne discovered that the temperature which affects human beings is very different from that indicated by the ordinary thermometer. In view of the great importance of the humidity of the air in controlling our sensation of heat or cold, it was later naturally suggested that the readings of the wet-bulb thermometer should be used to indicate the sensible temperature, this instrument, as is well known, reading lower than the dry-bulb thermometer under ordinary conditions because of the evaporation of water from its surface. Although the wet-bulb readings do not indicate what human beings feel, because the wet-bulb thermometer is not an organic body, with internal heat, varying conditions of covering, of health, of work, of exposure, of radiation, and so on, yet these readings have been generally spoken of as if they really expressed the temperature which is felt by us. If the expression "sensible temperatures" is to be used for the temperatures which the human body feels, we ought not to call wet-bulb readings by that name.

In view of the importance of the temperatures recorded by means of the wet bulb, the Weather Bureau, in September, 1895, began to tabulate them on the daily weather maps, but this practice was discontinued after a time. Although these readings are not satisfactory, Hann recommends that they be included among the other temperature records in climatic tables, because they furnish "a convenient index of the heat which is actually felt by the human body." Professor Harrington has constructed a chart of the July wet-bulb temperatures for the whole of the United States, and another which shows the reduction of the temperature by evaporation in the same month. Professor Willis L. Moore, Chief of the Weather Bureau, has also published a chart showing the average actual and sensible temperatures of the United States for the summer season, deduced from eight years' observations at 8 A.M. and 8 P.M., Eastern standard time. In Death Valley, Cal., the observers of the Weather Bureau experienced five days in the summer of 1891 on which the maxima were 122°. The wet-bulb thermometer, however, indicated only 73° to 77°, so that the temperature actually felt by any one who was in a favourable location, *i. e.*, protected against heating by direct sunshine, was almost as low as that of an ordinary summer afternoon, in so far as evaporation alone was concerned. On August 4 and 5, the maxima in Death Valley were 117.9° and 113.9°, but the readings of the wet-bulb thermometer were only 69.8° and 66.9°.

Quite recently a novel form of instrument has been suggested, which is designed to approximate much more closely to the actual conditions than does the wet-bulb thermometer. This instrument, called the "Deperditometer," is to be a porous cell, covered with some organic membrane, and filled with distilled water. The water is to be kept at the temperature of the body by means of a gas jet, automatically regulated. The amount of heat needed to keep the cell at the proper temperature is to be a measure of the quantity of heat lost from the cell.

The most careful instrumental study of the temperature, as felt by the human body, was made a few years ago by Vincent, of

Brussels. Vincent slowly rubbed the palm of his left hand and his cheek with the small cylindrical bulb of a thermometer until the latter indicated a constant temperature, the skin being exposed to wind and to sunshine during the observations. On the basis of 365 observations, Vincent obtained the following formula:

$$H = 26.5 + 0.3\,L + 0.2\,S - 1.2\,W$$

Where H = temperature of the skin, L = air temperature, S = insolation (excess of black bulb over air temperature), and W = wind velocity in metres per second. Vincent's results, while really applicable to his individual case only, are noteworthy because they are the first of the kind obtained. The factors taken into account in the formula, it will be observed, are but three, and do not include atmospheric humidity.

The importance of finding some expression for the sensation of temperature led Professor Abbe to suggest that, in climatic tables, days should be classified according to the sensation which they produce in the observer, as, for example, such feelings as "harshness," "rawness," "mildness," "oppression," "cheerfulness," etc. In 1876, J. W. Osborne proposed a definite scale of "subjective temperatures" to be used in such observations, there being twenty different degrees in the scale, running from 20., *Intolerably hot*, to 1., *Unbearably cold.* Obviously, it would be impossible to have observations of this sort comparable, because each observer would differ so much in his own feelings of cold and heat, of exhilaration and depression. Professor Abbe has also suggested noting on a diagram, on which relative humidities and temperatures are indicated by the ordinates and abscissæ, the points where, on any day or days, the observer feels like saying, "The weather is perfect." In this way he has himself drawn a diagram which, for winds of varying velocities, shows for him a condition of temperature and relative humidity which is perfectly comfortable. This method makes it possible for each individual to draw his own personal diagram of what Professor Abbe calls "curves of comfort." Curves may, of course, also be drawn for conditions of discomfort, such as extreme rawness, suffocating heat, etc.

There have been several interesting suggestions in connection with the feeling of heat or cold as dependent upon temperature and relative humidity, without taking into account the remaining factors in the problem. Thus Lancaster, Chief of the Belgian Meteorological Service, has tried to determine what degrees of relative humidity give certain high temperatures an oppressive feeling of heat. The observations were made in calm weather, and relate to one individual, in Belgium. Lancaster found, for his own feelings, that the heat became very oppressive when the relative humidity rose above the following percentages for the accompanying temperatures:

Fahr........	84°	82.5°	80.5–77°	75–73.5°	71.5°–70°
Rel. Hum....	45%	50%	65%	70%	75%

Comparing these conditions with those of a typical moist tropical climate, Lancaster found that at Vivi, in the Congo Free State, the average relative humidity with a temperature of 86°F. is 59% during December–May; while in Belgium for the same temperature it is 36%. If the relative humidity in Belgium rises to 40% at a temperature of 86°, the heat becomes insupportable.

Another recognition of the importance of relative humidity as a factor in climate is Ravenstein's classification of climates on the basis of relative humidity and temperature. He suggests sixteen *hygrothermal* types for the earth as a whole, ranging from *hot* (temperature 73° and over) *and very damp* (humidity 81% or more) through *warm and moderately damp*, *cool and very damp*, etc., to *cold and very dry*. One extreme (*hot and very damp*) is represented by Batavia; the other (*cold and very dry*) by the Pamir.

The temperatures which we feel are really the complex resultant of many variables. The suggestion of a New York newspaper, that the Weather Bureau, in its forecasts of temperature, should take account of temperature, wind velocity, and humidity, so that a single statement “would express just what people mean when they say that the day is hot or cold,” is absurd on the face of it. The sensible temperature is so complex and so individual that no such forecast can be made which would be of any general value whatever.

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CONCERNING SEXTANT OBSERVATIONS FOR DETERMINING GEOGRAPHICAL POSITIONS.

BY

G. W. LITTLEHALES.

1. Besides incidental and variable errors, all sextant observations are subject to certain fixed and generally unknown errors, as follows:

(1) Errors of the instrument. These are comprised in:

- (*a*) Index error; that is, the uncertainty of the index error as found or used.
- (*b*) Shade glasses; this can be corrected in some instruments by reversing, but to do so is not always convenient. The colored eye-piece is free from this error because affecting alike the direct and the reflected image.
- (*c*) Telescope; collimation error, or lack of parallelism with plane of instrument; this, like the index error, we must expect to exist in some degree.
- (*d*) Eccentricity of instrument; this can be determined with considerable accuracy if the proper appliances are provided, but it is not conveniently found, and is commonly neglected.